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Quaternary blended cement mortars containing wood ash, glass and slag powders

Eethar Thanon Dawood* and Marwa Saadi Mhmood

Building and Construction Engineering Technical College of Mosul, Northern Technical College of Mosul, Northern Technical University, 00964 Mosul, Iraq

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ABSTRACT

A quaternary supplementary cementitious materials as partial replacement of ordinary Portland cement decreases CO_2 emission. This paper has investigated the properties of mortars made from different quaternary blends of wood ash, steel slag powder and glass powder with ordinary Portland cement at different replacement levels of 0, 24, 25, and 30% by weight of the binder. The blended mortar mixtures tested for flow, compressive strength and density. The results showed that the flow of mortars is decreased with the combined use of steel slag powder, glass powder, and wood ash compared with control mix. Compressive strength reduced with the combination of steel slag powder, glass powder and wood ash but this reduction effects is acceptable especially at 24% replacement contain super-plasticizer compared with the ecological benefit.

KEYWORDS

quaternary, supplementary cementitious materials, steel slag powder, glass powder, wood ash, ecological effects

1. INTRODUCTION

Despite of concrete importance as a construction building materials around the worlds because of widespread availability of its constituents, its versatility, its durability, and its adaptability, but it is side effects for environment concrete, use large volumes of raw materials that are quarried from the earth, their production requires a large amount of energy, and the manufacture of Portland cement emits a large amount of CO_2 [1]. The production of one ton of cement requires about 1.6 metric ton of raw materials [1–3]. So that, reusing waste constitutes substitute of cement as a supplementary cementitious materials, this materials is a by-products of other industrial processes or wastes like (Glass Powder (GP), Steel Slag Powder (SSP), and Wood Ash (WA)), an important challenge in order to reach a more sustainable environment. Subsequently to their combination with cement, different pozzolans have diverse influences on the properties of cement based materials. For instance, steel slag decreased the workability of concrete [2], also WA decreased the workability, that extra water needed to be added [3]. On the other hand, mortar flow was slightly increased with increased in GP addition [4]. Additionally, GP produces a denser matrix, which improves the durability property of concrete [5]. On the contrary, steel slag hydration products cannot densify the skeleton structure of the matrix resulted in higher porosity [6]. Additionally, concrete specimens absorbed more water as the WA content increased [7]. while the partial replacement of cement by 10% by weight of GP leads to an increase of physico-mechanical properties of mortars [8]. At the same time, the replacement ratio of WA with 10% replacement mortar has the highest strength [9]. Also steel slag replacement up to 10% does not show any adverse effect of the early as well as latter strength [10].

An attempt to fully utilize the synergistic effects of these materials to reduce the inherent shortcomings of each of these materials on the properties of concrete necessitates research on

*Corresponding author.
E-mail: ethar2005@yahoo.com

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Quaternary blends of cementations materials. In quaternary blends, three different materials are combined in appropriate proportions to partially replace cement.

Additionally, high cement replacement could be achieved in more than one material with improvement the performance of concrete at reduced cost, when compared to some cement mixes which contain only one pozzolanic material. This study aims to clarify the effect that blended cements with four components have on the flow-ability and compressive strength of mortars.

The objectives of this work are to prepare mortar mixes for each level of cement substitution and test their flow and compressive strength. Additionally, compare the results of mortars for each ratios replacement for steel slag, GP, and WA. Determine whether the three materials are suitable to combine together within the mix. Also, investigate the optimal rate of substitution of both materials in the combined state.

2. MATERIALS

2.1. Cement

Locally available cement is used to produce mortar. This cement was obtained from Badoush expansion cement factory. The physical properties are shown in Table 1. Besides, the chemical compositions are shown in Table 2. Both chemical and physical characteristics are in compliance with Iraqi Standard Specification, IQS 5/1984, [11].

Table 1. Physical characteristics of ordinary Portland cement

Test	Produced cement	Limilts of IQS 5/1984 [11]
Initial setting time (minute)	143	min 45
Final setting time (minute)	175.5	max 600
Fineness blain (cm^2/g)	3,398	More than 23,000
Compressive strength		
3 days (N/mm^2)	31.64	≥16
7 days (N/mm^2)	39.30	≥ 24

Table 2. Chemical composition of ordinary Portland cement

Constituent	Content percent (%)	Limits of IQS 5/1984 [11]
CaO	62.5	–
SiO_2	20.91	–
Al_2O_3	5.96	–
MgO	3.8	≥5.0%
Fe_2O_3	2.53	–
SO_3	2.32	≥2.8%
L.O.I	1.45	≥4.0%
C_3S	39.5	–
C_2S	30.16	–
C_3A	11.5	–
C_4AF	7.7	–

2.2. Glass powder

Particles finer than 63 µm sieving on sieve No. 230 (63 µm) and 2.62 g/cm^3 specific gravity is used in this work. Chemical analysis of GP is presented in Table 3.

2.3. Steel slag powder

Particles finer than 63 µm sieving on sieve No. 230 (63 µm) and specific gravity of 3.47 g/cm^3 is used in this work. Chemical analysis of steel slag powder (SSP) is presented in Table 4.

2.4. Wood ash

Particles finer than 63 µm sieving on sieve No. 230 (63 µm) and specific gravity of 2 g/cm^3 is used in this work. Chemical analysis of WA is presented in Table 5.

2.5. Sand

The natural river sand used as a fine aggregate was supplied from Kanhash region in Mosul. The specific gravity, fineness modulus and absorption of sand are 2.66, 3 and 1%, respectively. The grading limits are according to IQS 45/1984 and given in Table 6.

Table 3. Chemical composition of glass powder

Constituent	Content Percent (%)	Pozzolan class N ASTM C618 [12]
CaO	10.43	–
SiO_2	73.7	–
Al_2O_3	0.72	–
MgO	1.27	–
Fe_2O_3	0.38	–
SO_3	–	4
Na_2O	12.71	–
K_2O	0.70	–
TiO_2	0.086	–
L.O.I	–	10
$SiO_2 + Al_2O_3 + Fe_2O_3$, min. percent	74.8	Min. 70

Table 4. Chemical composition of steel slag powder

Constituent	Content Percent (%)	ASTM C989 [13]
CaO	44.27	–
SiO_2	18.73	–
Al_2O_3	2.18	–
MgO	5.54	–
Fe_2O_3	22.69	–
SO_3	0.45	Max 2.5
Na_2O	–	–
K_2O	0.01	–
L.O.I	6.12	10
Total Alkalies ($Na_2O + 0.658\ K_2O$)	0.00658	Min 0.60% Max 0.90%

Table 5. Chemical composition of wood ash

Constituent	Content Percent (%)	Pozzolan class N ASTM C618 [12]
CaO	18.15	–
SiO_2	44.13	–
Al_2O_3	8.2	–
MgO	2.7	–
Fe_2O_3	7.6	–
SO_3	2.3	4
Na_2O	2.9	–
K_2O	4.9	–
TiO_2	0.3	–
L.O.I	9.4	10
$SiO_2 + Al_2O_3 + Fe_2O_3$, min. percent	74.8	Min. 70

Table 6. Grading of fine aggregate

Sieve No. (mm)	Cumulative passing (%)	Limits of IQS 45/1984 [14]
3/8 ''	100	90–100
No. 4 (4.75)	92	90–100
No. 8 (2.36)	88	85–100
No. 16 (1.18)	83	75–100
No. 30 (0.60)	66	60–79
No. 60 (0.30)	23	12–40
No. 100 (0.15)	7	8–10

2.6. Super-plasticizer

High performance super-plasticizer with slump retaining concrete admixture, super-plasticizer from (Sika ViscoCrete hi-tech 1316), was used to establish the desired workability of mixes. Technical descriptions of this type of super-plasticizers are shown in Table 7.

2.7. Tap water

Normal tap water was used in this study for mixing and normal curing.

2.8. Mix proportion

A total of 5 different mortar mixtures of constant binder aggregate ratio (1:2.75) and water-binder ratio was added to achievement the flow-ability for each mix within the range 105–115%.

Table 7. Technical description of super-plasticizer

Appearance	Brownish liquid
Structure of the material	Modified polycarboxylates based polymer
Density	1.098 ± 0.01 g/cm^3
PH Value	4.5–5
Dosage	For soft plastic concrete: 0.4–1%, For self-compacting concrete: 1–1.3% by weight of binder
Freezing point	−5 °C

The first category constituted mortar mixture (control) containing plain ordinary Portland cement as the only binder. In the second category, ordinary Portland cement was partially replaced by SSP, GP, and WA by weight in the quaternary levels.

3. THE METHOD

3.1. Flow test on mortar

The standard test method for flow of hydraulic cement mortar, determines how much a mortar sample flows when it is unconfined and consolidated according to ASTM C1437, [15]. Water binder ratio varied to maintain flow-ability of mortars between 105 and 115% for all the mixes.

3.2. Compressive strength test

A set of three cubes were tasted in each case and the average value of these three was reported. Compressive strength test of mortar were done as per ASTM C109 [16]. Experimental set up for compression tests in mortar. Samples of mortar were tested for compressive strength at 7 and 28 days.

4. TEST RESULTS AND DISCUSSION

4.1. Effects of blending on the flow of mortars

Results of flow illustrated in Tables 8 and 9 for 5 mixes without super-plasticizer and with super-plasticizer respectively observed when the addition of SSP, GP, and WA need more water to maintain the flow between 105 and 115%, the effect of quaternary of these materials need more water demand to obtain a similar.

Flow-ability and when increased the content of WA and SSP, mixes consumed more water especially in mix A4 with 14% SSP and 10% WA, due to the irregular shape of the ash particles [3]. These results agree with the findings by Naveen Saladi [17], where WA was reported to have reduced workability due to its high water demand. While, the effects of increased GP does not obvious compared with adding as binary blended cement. Besides, SSP in quaternary blended cement when increased with GP increased at the same time, the workability increased adverse when addition alone.

It is expected that the flow with Super-plasticizer will give similar trend. But the results indicate with increased the WA do not need more water demand to maintain the same workability adverse with increased SSP due to the roughness surface textures of SSP [18, 19].

4.2. Effect of blending on the compressive strength of mortars

The compressive strengths of blends and control cement mortars are shown in Tables 8 and 9 for 5 mixes without super-plasticizer and with super-plasticizer respectively.

Table 8. Test results of mortar mixes without super-plasticizer

Mix No.	Cement (kg/m^3)	Replacement ratio (kg/m^3)			W/CM (%)	Flow (%)	Compressive strength (Mpa)		Density (gm/cm^3)
		SSP	GP	WA			7 days	28 days	28 days
A0	500	–	–	–	0.58	111	21.038	31.26	2.138
A1	380	50	40	30	0.6	106.5	13.49	18.89	2.161
A2	380	10	6	8	0.6	110.5	13.096	18.12	2.129
A3	375	60	30	35	0.6	111	12.48	21.04	2.175
A4	350	70	30	50	0.62	115	5.3	7.37	2.076
A5	350	75	45	30	0.6	115	9.4	16.53	2.152

Table 9. Test results of mortar mixes with super-plasticizer

Mix No.	Cement (%)	Replacement levels (%)			W/CM (%)	SP (%)	Flow (%)	Compressive strength (Mpa)		Density (gm/cm^3)
		SSP	GP	WA				7 days	28 days	28 days
A0	100	–	–		0.5	0.8	115	28.705	35.007	2.153
A1	76	10	8	6	0.5	0.8	112.5	24.84	30.33	2.149
A2	76	10	6	8	0.5	0.8	113.2	18.29	22.54	2.137
A3	75	12	6	7	0.5	0.8	111	21.85	26.65	2.136
A4	70	14	6	10	0.5	0.8	115	15.96	22.9	2.124
A5	70	15	9	6	0.5	0.8	108.7	17.5	20.1	2.201

At 7 days and 28 days, all the quaternary blends of SSP, GP and WA exhibited lower compressive strength than the control.

The strength reduction became more pronounced as the WA content increased especially in mix A4 with 14% steel slag and 10% WA, this is attributed to higher percentages extra water is needed to keep an acceptable workability, however here the higher Water to Cement ratio (W/C) ratio causes lower compressive strength [3, 18–20].

The results test of compressive strength at 28 days showed the mix A3 is the best replacement compared with other mixes adverse mix A4. The results with adding super-plasticizer at 24% replacement ratio in mix A1 and mix A2 showed with increased WA content compared GP, compressive strength decreased at 7 days and 28 days. But, the results with adding super-plasticizer at 30% replacement ratio in mix A1 and mix A2 showed with increased SSP content compared WA, compressive strength decreased 28 days this mean WA enhancement the later age strength. Figure 1 illustrates the relationships between the SSP, GP, and WA on compressive strength of mortar (without super-plasticizer). Figure 2 shows the relationships between the SSP, GP, and WA on compressive strength of mortar (with super-plasticizer).

4.3. Effect of blending on the density of mortars

The density of blends and control cement mortars at 28 days are shown in Tables 8 and 9 for 5 mixes without super-

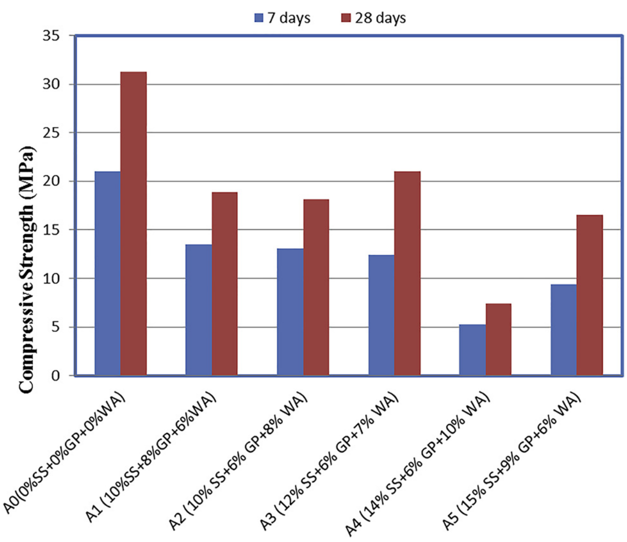

Fig. 1. Effects of steel slag powder, glass powder, and wood ash on compressive strength (without super-plasticizer)

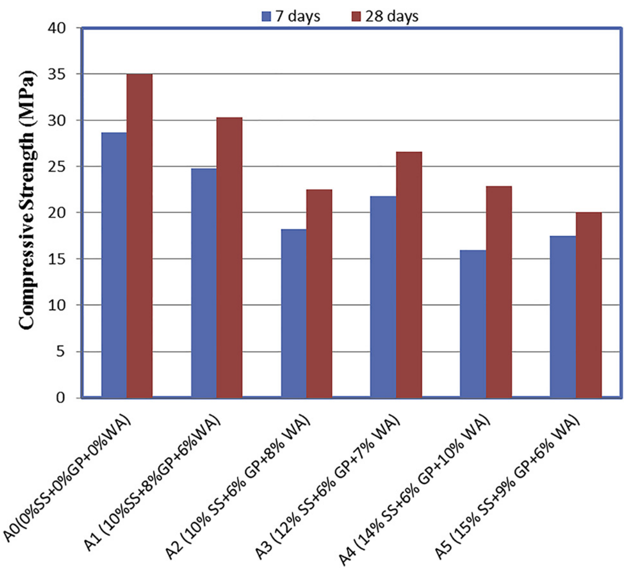

Fig. 2. Effects of steel slag powder, glass powder, and wood ash on compressive strength (with super-plasticizer)

plasticizer and with super-plasticizer respectively. The density increased obviously with increased SSP. While, with WA content increased led to density decreased. This is surely related to the specific gravity for each cementitious materials and its percentage in the mix [7, 19, 20].

5. CONCLUSIONS

The following conclude it from the results of this study:

1. Quaternary blends of SSP, GP and WA produced mortar flow, need extra water demand than control mix and with increasing WA content, mix consume more water. However, a combination of the triple produced flow less than control mix, but with increased GP content, the mix consumed water demand less than compared with increased WA content at similar flow;
2. The use of WA in mortar results in reduction in compressive strength at 7 and 28 days especially, the effects of WA in mix A2 than A1 when compared the effects with GP;
3. The effect of WA decrease obviously in density of mortars adversely SSP increases the density of mortars;
4. The use of quaternary blends of SSP, GP and WA in the order of 10, 8, and 6% as partial replacements of cement reduces the compressive strength by about 14% only while allowing to give green mortar with total replacements of 24% of cement.

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